CLAIMS:

1 A method for creating a zone of permanently altered refractive index characteristics in an optical waveguiding device made of glass material and having at least one core and at least one cladding, using a beam which is generated by a focused pulsed laser light source having:

- (i) a wavelength greater than the absorption edge of the glass material;
- (ii) a pulse width of less than 1 picosecond, and a pulse energy of between 1 nanojoule and 1 millijoule; and
- (iii) capable of achieving a peak pulse intensity within a defined focal region; comprising the steps of:
- (a) aligning said laser beam focal region with a defined target region within the waveguiding device; and
- (b) operating said laser light source with the peak pulse intensity thereof and a repetition rate thereof selected to accumulate heat and to soften the glass material at the target regions and to thereby induce permanent refractive index changes in the waveguiding device at the target region.

2. The method according to claim 1 wherein said step (b) comprises the steps of:

- (c) reducing said peak pulse intensity to below the threshold for inducing
- (d) orienting said focal region to be substantially perpendicular to a longitudinal axis of said at least one core;
- (e) sweeping said focal region over said waveguiding device while measuring multiphoton fluorescence from said at least one core, such that a maximum fluorescence level is indicative of location alignment of said focal region with said at least one core; and
- (f) using said orientation and location alignments as spatial references for sweeping said focal region, while setting said peak pulse intensity to at least the threshold for inducing permanent refractive index changes in said waveguiding device, to create said zone, said zone having an orientation and location within said waveguiding device corresponding to the orientation and location respectively of said focal region.

3. The method according to claim 2 wherein said pulsed laser light source is operated at a pulse repetition rate of between 500 Hz and 1 GHz.

4. The method according to claim 1 wherein said laser light source is a laser system in which the output of a frequency-doubled Erbium-doped fiber laser is amplified in a laser regenerative amplifier that is based on a Ti:Sapphire gain material.

5. The method according to claim 1 wherein said laser light source has a beam diameter of from 0.1 to 10mm.

6. The method according to claim 1 wherein said focused pulsed laser light is focused with a lens, axicon, focusing mirror, or combinations thereof to achieve desired spatial relationship of the focal region with respect to the target region.

7. The method according to claim 6 wherein said lens, axicon, or focusing mirror has a focal length from 1 to 30mm and a numerical aperture from 0.05 to 1.3.

8 . The method according to claim 1 wherein said pulse width is less than 200 femtoseconds.

9. The method according to claim 3 wherein said pulse repetition rate is from 1kHz to 100MHz, said repetition rate being selected based on laser parameters and glass material properties to deliver pulses faster than the thermal diffusion time of the target region so as to allow heat to accumulate and soften the glass material.

10. The method according to claim 1 wherein larger material restructuring permitted under heat accumulation conditions leads to larger thermal activation barriers for the glass material to relax back to original form and thereby significantly increase the lifetime of any written structure in the material.

11. The method according to claim 1 wherein said peak pulse intensity threshold for inducing permanent refractive index changes is at least 10^{10} W/cm^2.

12. The method according to claim 1 wherein said optical waveguiding device is selected from the group of optical waveguiding devices consisting of: an optical waveguide

embedded in a glass substrate; a conventional optical fiber; a polarization maintaining optical fiber; an optical fiber with a Germanium enriched core; a hydrogen or deuterium loaded optical fiber; a W-fiber; a multiple cladded fiber; a photonics crystal fiber; a waveguiding device comprised of intersecting at least two optical waveguides; a taper coupler; a rare earth doped fiber, and doped glasses designed for enhanced multiphoton absorption and lower thresholds for femtosecond laser induced material modification.

13. A method for creating a zone of permanently altered refractive index characteristics in an optical waveguiding device made of glass material and having at least one core and at least one cladding, using beams generated by at least two focused pulsed laser light sources, each having:

(i) a wavelength greater than the absorption edge of the glass material;

(ii) a pulse width of less than 1 picosecond, and a pulse energy of between 1 nanojoule and 1 millijoule; and

(iii) capable of achieving a peak pulse intensity within a defined focal region; comprising the steps of:

(a) aligning the focal region of each said laser beam with a defined target region within the waveguiding device; and

(b) operating said laser light sources with the combined peak pulse intensity thereof and a repetition rate thereof selected to accumulate heat and to soften the glass material at the target regions and to thereby induce permanent refractive index changes in the waveguiding device at the target region.

14. The method according to claim 13 wherein said step (b) comprises the steps of:

(c) reducing said peak pulse intensity of each laser light source such that the combination of the peak pulse intensities is below the threshold for inducing permanent refractive index changes in said waveguiding device;

(d) orienting each of said focal regions to be substantially perpendicular to a longitudinal axis of said at least one core;

(e) sweeping said focal regions over said waveguiding device while measuring multiphoton fluorescence from said at least one core, such that a maximum fluorescence level is indicative of location alignment of said focal regions with each other and with said at least one core; and

(f) using said orientation and location alignments as spatial references for sweeping said combined focal regions, while setting said peak pulse intensities to bring the combined peak pulse intensities to at least the threshold for inducing permanent refractive index changes in said waveguiding device, to create said zone, said zone having an orientation and location within said waveguiding device corresponding to the orientation and location respectively of said combined focal regions.

15. The method according to claim 14 wherein each of said pulsed laser light sources is operated at a pulse repetition rate of between 500 Hz and 1 GHz.

16. The method according to claim 13 wherein each of said laser light sources is a laser system in which the output of a frequency-doubled Erbium-doped fiber laser is amplified in a laser regenerative amplifier that is based on a Ti:Sapphire gain material.

17. The method according to claim 13 wherein each of said laser light sources has a beam diameter of from 0.1 to 10mm.

18. The method according to claim 13 wherein the focused pulsed laser light from each of said laser light sources is focused with a lens, axicon, focusing mirror or combinations thereof.

19. The method according to claim 18 wherein each said lens has a focal length from 1 to 30mm and a numerical aperture from 0.05 to 1.3.

20. The method according to claim 13 wherein the focused pulsed laser light from each of said laser light sources is focused with reflective optics.

21. The method according to claim 13 wherein said pulse width is less than 200 femtoseconds.

22. The method according to claim 15 wherein said pulse repetition rate is from 1kHz to 100MHz.

23. The method according to claim 13 wherein said peak pulse intensity threshold for inducing permanent refractive index changes is at least 10^{10} W/cm^2.

24. The method according to claim 13 wherein said optical waveguiding device is selected from the group of optical waveguiding devices consisting of: an optical waveguide embedded in a glass substrate; a conventional optical fiber; a polarization maintaining optical fiber; an optical fiber with a Germanium enriched core; a hydrogen or deuterium loaded optical fiber; a W-fiber; a multiple cladded fiber; a photonics crystal fiber; a waveguiding device comprised of intersecting at least two optical waveguides; a taper coupler; a rare earth doped fiber; and doped glasses designed for enhanced multiphoton absorption and lower thresholds for femtosecond laser induced material modification.

25. A method for creating a zone of permanently altered refractive index characteristics in an optical waveguiding device made of glass material and having at least one core and at least one cladding, using beams generated by at least two focused pulsed laser light sources, each having:

(i) a wavelength greater than the absorption edge of the glass material;

(ii) a pulse width of less than 1 picosecond, and a pulse energy of between 1 nanojoule and 1 millijoule; and

(iii) capable of achieving a peak pulse intensity;

comprising the steps of:

(a) combining said laser beams to create a single laser beam having a focal region;

(b) aligning said single laser beam with a defined target region within the waveguiding device; and

(c) operating said laser light sources with the combined peak pulse intensity thereof and a repetition rate thereof selected to accumulate heat and to soften the glass material at the target regions and to thereby induce permanent refractive index changes in the waveguiding device at the target region.

26. The method according to claim 25 wherein said step (c) comprises the steps of:

(c) reducing said peak pulse intensity of each laser light source such that the combination of the peak pulse intensities at said focal region is below the

threshold for inducing permanent refractive index changes in said waveguiding device;

(d) orienting said focal region to be substantially perpendicular to a longitudinal axis of said at least one core;

(e) sweeping said focal region over said waveguiding device while measuring multiphoton fluorescence from said at least one core, such that a maximum fluorescence level is indicative of location alignment of said focal region with said at least one core; and

(f) using said orientation and location alignments as spatial references for sweeping said focal region, while setting said peak pulse intensities to bring the combined peak pulse intensity to at least the threshold for inducing permanent refractive index changes in said waveguiding device, to create said zone, said zone having an orientation and location within said waveguiding device corresponding to the orientation and location of said combined focal region.

27. The method according to claim 26 wherein at least one of said pulsed laser light sources is operated at a pulse repetition rate of between 500 Hz and 1 GHz.

28. The method according to claim 25 wherein each of said laser light sources is a laser system in which the output of a frequency-doubled Erbium-doped fiber laser is amplified in a laser regenerative amplifier that is based on a Ti:Sapphire gain material.

29. The method according to claim 25 wherein each of said laser light sources has a beam diameter of from 0.1 to 10mm.

30. The method according to claim 25 wherein the focused pulsed laser light from each of said laser light sources is focused with a lens, axicon, focusing mirror or combinations thereof.

31. The method according to claim 30 wherein each said lens has a focal length from 1 to 30mm and a numerical aperture from 0.05 to 1.3.

32. The method according to claim 25 wherein the focused pulsed laser light from each of said laser light sources is focused by reflective optics.

33. The method according to claim 25 wherein said pulse width is less than 200 femtoseconds.

34. The method according to claim 27 wherein said pulse repetition rate is from 1kHz to 100MHz.

35. The method according to claim 25 wherein said peak pulse intensity threshold for inducing permanent refractive index changes is at least 10^{10} W/cm^2.

36. The method according to claim 25 wherein said optical waveguiding device is selected from the group of optical waveguiding devices consisting of: an optical waveguide embedded in a glass substrate; a conventional optical fiber; a polarization maintaining optical fiber; an optical fiber with a Germanium enriched core; a hydrogen or deuterium loaded optical fiber; a W-fiber; a multiple cladded fiber; a photonics crystal fiber; a waveguiding device comprised of intersecting at least two optical waveguides; a taper coupler; a rare earth doped fiber; and doped glasses designed for enhanced multiphoton absorption and lower thresholds for femtosecond laser induced material modification.

37. An optical waveguiding device having a core, a cladding, and at least a single zone therein at which the refractive index characteristics of the waveguiding device have been permanently altered, whereby the altered waveguiding device can serve as an attenuator, an optical tap, a polarimeter, or a Bragg grating.

38. The optical waveguiding device of claim 37 wherein said zone is within said core.

39. The optical waveguiding device of claim 37 wherein said zone is located within said cladding.

40. The optical waveguiding device of claim 37 wherein said zone is located at the interface of said cladding and said core.

41. The optical waveguiding device of claim 37 wherein said zone is located within an evanescent region of said waveguiding device.

42. The optical waveguiding device of claim 37 wherein said zone is located at a specific location with said core, within said cladding, or at the interface of said core and said cladding, and said zone is oriented perpendicular to a longitudinal axis of said core, at an angle to said longitudinal axis, or parallel to said longitudinal axis.

43. An optical attenuator comprising an elongated waveguiding device having a core, a cladding, and an optical transmission axis extending along the waveguiding device, said waveguiding device also comprising a single zone therein wherein the index of refraction of the device has been permanently altered such that a controlled portion of light transmitted along said core is removed therefrom, thereby leaving a controlled remainder of the light propagating in the core.

44. The optical attenuator according to claim 43 wherein said zone is oriented perpendicular to said transmission axis, or at an acute angle to said transmission axis.

45. The optical attenuator according to claim 43 wherein said zone is located in an *evanescent region of the cladding.*

46. An optical tap comprising an elongated waveguiding device having a core, a cladding, and an optical transmission axis extending along the waveguiding device, said waveguiding device also comprising a single zone therein wherein the index of refraction of the device has been permanently altered such that a portion of light transmitted along said core is removed therefrom.

47. The optical tap according to claim 46 wherein said zone is oriented perpendicular to said transmission axis, at an acute angle to said transmission axis, or parallel to said transmission axis.

48. The optical tap according to claim 46 wherein said zone is located in said core, said cladding, at the interface between said core and said cladding, or in an evanescent region of the cladding.

49. A power meter arrangement for identifying power levels in an optical fiber comprising an optical tap according to claim 46 in combination with: detector means located adjacent said fiber and radially aligned with said zone, said detector means being adapted to receive

light removed from said fiber at said zone and to create a signal proportional to the removed light; and reader means connected to said detector means and adapted to equate said signal to a power level.

50. An optical polarimeter comprising an elongated waveguiding device having a core, a cladding, and an optical transmission axis extending along the waveguiding device, said waveguiding device also comprising at least two longitudinally spaced apart zones therein wherein the index of refraction of the device has been permanently altered, said zones having azimuthal angles spaced at substantially 90 degrees, and each of said zones being oriented substantially at a Brewster angle relative to said transmission axis, causing it to reflect s-polarized light out of said core, such that said polarimeter is capable of measuring two orthogonal light polarization states therein.

51. The optical polarimeter of claim 50 wherein said azimuthal angles are spaced at an angle different from 90 degrees to reduce polarization-dependant losses through the balancing of the polarization dependencies of the zones.

52. The optical polarimeter of claim 50 including four of said zones located in said core, spaced apart along said transmission axis with the azimuthal angles thereof spaced at substantially 45 degrees, with each of said zones being oriented substantially at a Brewster angle to said axis, causing it to reflect s-polarized light out of said core, and including a $\lambda/2$ wave plate in said core located between any adjacent pair of said zones, the polarization axis of said $\lambda/2$ wave plate having an orientation along the s-polarization direction of one zone of said adjacent pair, such that said polarimeter is capable of measuring all four Stokes parameters which completely specify light polarization states in said polarimeter.

53. A method for improving coupling between a waveguide and an optical source having characteristic optical mode field properties by modifying the refractive index characteristics of the waveguide at or near the interface point by the method of claim 1 to thereby reshape the waveguide mode field properties to match those of the source.

54. A method for improving coupling between two waveguides having different refractive index profiles and corresponding optical mode field properties by modifying the refractive index characteristics of at least one of the waveguides at or near the interface point by the

method of claim 1 to reshape the mode field properties of said at least one of the waveguides to match the final waveguide mode field properties.

55. A waveguide collimator comprising a waveguide whose refractive index characteristics have been altered near an end face thereof to substantially enlarge the mode field diameter thereof, thereby reducing the divergence of the light exiting the waveguide.

56. The method according to claim 1 including the step of initially applying mechanical stress to said waveguiding device and then removing said mechanical stress once said zone of altered refractive index characteristics has been created.

57. The method according to claim 1 including the step of initially applying an electric field to said waveguiding device and then removing said electric field once said zone of altered refractive index characteristics has been created.

58. The method according to claim 1 including the step of positioning a volume of index matching fluid between said laser light source and said waveguiding device such that said beam will pass through said fluid prior to reaching said target region.